stands in their way is the lack of faith and of courage on the part of the present directing agencies. Probably the most practical suggestion of immediate value that has been made is that the various scientific societies in any town should arrange meetings for study and discussion—the discussion which seeks agreements and does not emphasise differences—and that the underlying, but not obtrusive, object of the meetings should be the progressive connecting of science with individual and corporate conduct.

The second question has many factors in common with the first. The British Association has suffered from the mental reaction which set in a quarter of a century ago. It is a much smaller factor in the thought and life of the age than it was a generation ago. I think the first helpful change desirable is the recognition of a new principle in the selection of a president and in the making of his annual address. Above all things, the president should stand for the unifying of the sciences, and his address should make some definite contribution to that unity, even when it is built largely on the recent achievements of one section of knowledge.

It is only through a conception, becoming ever clearer, of this unity that science can become the "chief formative factor of modern life." The yearly appeal of a president may do much, but more would be achieved if a day were set apart for the study or discussion of the thoughts and facts he has communicated—a study or discussion, I say again, which should emphasise agreements and not differences.

Progress in this direction might receive a healthy impetus from the universities. They, too, have lost a considerable amount of influence. They are not, at home or abroad, leading humanity. The note of real universality is departing from them. Here again the first practical improvement will come from the manifestation of greater care in the selection of the principals of the attached colleges. They ought to be something more than skilled administrators. They, too, have a great unifying function.

This unifying work might be facilitated if there were periodical meetings of the various professors and lecturers for the study of unifying problems. That does not, I admit, promise to help them immediately to overcome the financial difficulties which are now laming them to a terrible extent and driving them to seek greater support from an overburdened State. But if the universities, encouraged by a steadily increasing enthusiasm for science locally and centrally, were themselves to become again great inspirers of thought, they would soon cease to be troubled by the lack of pence.

W. ROBERTSON.

Middlesbrough, December 29.

### Cohesion.

THE theory of cohesion put forward by Dr. Herbert Chatley in NATURE of August 18 is logically based on those of other investigators, and, consequently, does not involve any new element. In all these theories cohesion is made to depend on centrally directed forces which follow either the inverse square law of gravitation or electrical attraction, or that of some other inverse power higher than the second. Dr. Chatley says: "It is difficult to conceive of one force having all these properties, but perfectly simple to imagine an attraction and repulsion combined that will do so, provided that *the attraction decreases more slowly with separation than the repulsion.*" He takes the ground that the force of cohesion as stated by him is related to those following the inverse square law, and that the question of the relation between them is of great importance.

Now it is a matter of common observation that two free liquid spheres on coming into contact with each other always coalesce. The force which causes this is evidently a force *enveloping* their masses, and not a force attracting them. This enveloping property of surface tension was noticed by Maxwell and others; but the theory which makes it depend on molecular attraction renders it impossible to conceive of such a force as enveloping *molecular* masses.

The present writer has adduced (*Phil. Mag.*, June, 1921) very strong, if not conclusive, evidence that the same force which causes liquid spheres to coalesce also causes the free molecules of a gas to coalesce or cohere. It cannot, therefore, be explained by molecular attraction. The alternative is that *it is an elemental force acting, not in lines, but over areas.* As such it is a universal property of the surface of both liquid and solid mass extending to molecular dimensions.

Fortunately, however, there is very definite and easily verifiable evidence that cohesion, and adhesion also, is due to a surface force, whatever its nature may be, as can be seen from the following simple experiments which will be published later in fuller detail.

Spheres of mercury, ranging from 0·05 mm. to 1·5 mm. in diameter, were hung from a drop of water wetting a glass surface above. Each one fitted into an inverted hemispherical cavity in the water, with a well-defined angle in the contact circle where the water surface joined the mercury surface. With a specially adapted microscope the diameter of the sphere, the width of the contact circle, and the angle between its water arm and the vertical were measured. From these measurements, W, the weight of the mercury sphere, and T, the vertical component of the pull of the water surface on the mercury, were calculated for a large number of spheres. The results showed that for small spheres T greatly exceeded W, but tended to become equal to W when the spheres were at the point of falling off. The ratio T/W decreased gradually from about 6 to 1, thus showing that the surface force of the water pulling on the mercury in the periphery of the contact area was more than sufficient, except in the limit, to support the weight.

Similarly, mercury spheres, with diameters from 0·05 mm. to 2·25 mm., were suspended from a horizontal glass surface. They were attached to the glass either directly or by suspending them from water as before and allowing the water to evaporate. The mercury surface was joined to the glass surface in the periphery of a wide circular contact area, and formed a definite angle with the glass surface. Measurements were made as before, and W and T (for mercury) were calculated. The results showed that, as the spheres increased throughout the range, the ratio of T/W decreased from the surprisingly large number of more than 6000 to about 2. Had T, however, been calculated from $\sigma=270$ instead of $\sigma=547$, the decrease would have been from about 3000 to 1 as before, and hence 270 may be regarded as an approximate value of the surface tension of glass. The increasing values of T/W for the smaller particles would account for the persistence with which molecules of a gas condense on a glass surface.

Further, small particles of any insoluble solid become attached to any surface above by the evaporation of a connecting water drop; or, if the particles be clean and small, they become attached to any clean surface by simple contact with it. This is amply confirmed by extended observations.

Now there is no reason to think that the force of cohesion is not of the same nature in the case of two solids as it is in the cases of a liquid and a solid and

© 1922 Nature Publishing Group

of two liquids. Moreover, as it has been shown that two free molecules of a gas cohere (coalesce) from this same cause, it is justifiable to conclude that in all cases down to molecular dimensions cohesion is simply *a surface force pulling in the periphery of the contact area perpendicularly to that area.* It may be remarked also that these results furnish no evidence of the so-called molecular attraction.

By calculation this force binding two molecules of water together is $2{\cdot}05 \times 10^{-5}$ dynes; of mercury, $7{\cdot}7 \times 10^{-5}$ dynes. These agree with Dr. Chatley's statement that (molecular) cohesion is of the order of $10^{-6}$ dynes. Again, in the case of two molecules cohering in this manner the enveloping force can have a range not greater than two molecular diameters, while for larger molecular masses the range may be as great as three or four molecular diameters. It thus fulfils the condition for the range of action. In comparison with their gravitational attraction this force binding two water molecules together is of the order $10^{32}$ times as great. It is of the same order as the electrical attraction of two oppositely ionised molecules just before they come into contact. It causes a pressure on the interior molecular mass of the same order as the intrinsic pressure of the liquid. It does appear, then, that one force can be conceived as having all the properties of cohesion.

The conception of this force as a cause of molecular phenomena appears to be, in fact, fundamental. It solves the problem of surface tension; it explains, as we have seen, both cohesion and adhesion, and it accounts satisfactorily (*Phil. Mag., ibid.*) for the latent heat of condensation. But besides all this there is the remarkable coincidence that the force itself is located, or performs its function, in the precise area bounding free mass that the phenomena of reflection and refraction of light take place and electrons have their movement. These considerations give point to Dr. Chatley's concluding words: "It would appear that a complete solution of the macroscopic properties of matter would also solve the question of the inner structure of the molecules and atoms."

WILSON TAYLOR.

Physics Laboratory, University of Toronto,
Canada, November 15.

## The Resonance Hypothesis of Audition.

ADDITIONAL evidence in favour of the resonance hypothesis of audition has been found recently.

The study of long-distance telephony has shown that low-pitched notes travel more rapidly than do those of high pitch, owing to the impedance of the electrical circuits. Mixed tones must, therefore, arrive with phase relationships between the high and low tones quite different from those with which they started.

In spite of this, even such complex sounds as those composing human speech are found to suffer but small apparent change in quality and distinctness during transmission. And this statement appears to apply equally to wireless telephony, where similar changes of phase must occur.

These facts suggest that the ear responds to tones quite independently of their relative phases, and therefore that true harmonic analysis must take place in the organ of Corti. A survey of the different types of harmonic analysers used in physics, for tide production and the like, shows that such harmonic analysis is invariably performed by a series of some type of resonator. Presumably, therefore, since the ear can carry out harmonic analysis, it also must contain resonators.

To test the premises more thoroughly the following experiment was carried out:—

Two electrically driven tuning-forks, emitting pure tones, were connected to separate battery and switch circuits, and were mounted on separate tables, so that while they vibrated independently their tones entered the ear of the observer simultaneously. They were tuned so that their tones had rates of vibration in the ratio of 1 and 3, this ratio being chosen because of all pairs of tones these give the largest changes in the form of the sound wave-curve as the relative phases of the tones are changed. Thus with one phase relationship the sound wave-curve has a single sharp, well-marked peak, whereas with another phase relationship two peaks are found, having a trough between them. If, then, the ear is affected at all by the form of the sound wave-curve, these two tones, combined in different relative phases, should show it. The experiment was performed by causing the higher-toned fork to sound continuously, the lower-toned one being turned on and off at irregular intervals, so that the relative phases should be chance ones. No difference whatever in the quality of the sound could, however, be detected by the observer. The response of the ear appeared to be quite independent of the relative phases of the tones, and, therefore, we must conclude that the ear effects a true harmonic analysis by means of resonators.

If the above experiment is repeated with two sources of tones that are not free from overtones it is found that the ear does readily detect differences in the quality of the sound as the relative phases of the tones are altered. For example, if Helmholtz's syren is used with, say, 18 holes operating in the lower wind chest, and 6 holes in the upper, then there are found to be 18 regularly spaced positions where the lower tone predominates, and 18 intermediate positions in which the upper tone predominates.

These effects are produced by the summation and interference between the upper tone and the second harmonic overtone of the lower tone. When holes of both wind chests are exposed simultaneously, summation occurs, and the upper tone predominates, whereas when the holes of one chest alternate with those of the other, interference occurs which weakens the upper tone, so that the lower tone predominates.

Many years ago there was considerable controversy as to whether the ear could, or could not, detect difference of phase. The above experiments suggest that pure tone free from harmonics may have been used by one school, and impure tones containing harmonics by the other, because in this way their difference in opinion could be readily explained.

C. R. G. COSENS.
H. HARTRIDGE.

King's College, Cambridge.

## The Action of Sunlight.

IN NATURE of December 15 Sir Oliver Lodge is good enough to refer me to some experiments on the antiseptic action of sunlight which he carried out long ago in association with the late Prof. Marshall Ward. I have not yet been able to see the memoir to which Sir Oliver Lodge refers, but I believe that I am already well acquainted with it, and have been able to quote its essential findings on many occasions in connection with the demand for the abolition of the coal-smoke curse—thanks to an admirable account of Marshall Ward's methods and results, referred to the year 1892, in Sir James Crichton-Browne's "Light and Sanitation," an address delivered in Manchester in 1902 (Sherratt and Hughes, 27 St. Ann Street, Manchester). Particularly I value the last paragraph, in which Sir Oliver Lodge praises the anti-

© 1922 Nature Publishing Group